STATEMENT

for the dissertation for awarding the degree of Doctor of Physical Sciences in Professional field 4.1. Physical Sciences (Physics of Atoms and Molecules), within the procedure for defense in the Faculty of Physics (FoPh) of Sofia University "St. Kliment Ohridski" (SU)

This statement is prepared by Prof. Dr.habil. Alexander Alexandrov Dreischuh from the Faculty of Physics, Sofia University, Corr. Member of the Bulgarian Academy of Sciences, Member of the Scientific Jury in accordance with Order No. РД 38-249 / 20.05.2022 of the Rector of Sofia University.

Thesis title: "Critical phenomena and quantum metrology with strongly correlated quantum-optical systems".

Author of the thesis: Assoc. Prof. Dr. Petar Aleksandrov Ivanov

1. Submitted documents

The candidate Assoc. Prof. Dr. Petar Ivanov has submitted a thesis and an abstract, as well as the obligatory tables for the Faculty of Physics required according the Regulations on the Conditions and Procedure for Acquiring Scientific Degrees and Holding Academic Positions at Sofia University "St. Kliment Ohridski". Six other documents (CV, Declaration of Authorship, Statement of Compliance with the Minimum National Requirements and the Minimum Requirements of the Faculty of Physics, copies of the diplomas of Bachelor's and Doctor's degrees and a detailed description of the citations of the articles on which the dissertation is based) are also submitted.

The documents submitted by the candidate in the procedure comply with the requirements of the Law on the Acquisition of Scientific Degrees and Academic Positions at Sofia University “St. Kliment Ohridski” (RAPNS-ZAADSU).

2. Data about the applicant

In 2002, Mr. Ivanov graduated as a physicist from the Faculty of Physics of Sofia University. After regular PhD studies (2004-2008) he obtained a PhD degree. Since 2012 he has been a Senior Assistant Professor and since 2015 - an Associate Professor at the Department of Theoretical Physics of the Faculty of Physics. (I should mention that I was a member of the

scientific jury for this procedure and I got an excellent impression of his candidacy at that time.)

3. General description of the applicant's scientific achievements

The scientific publications included in the dissertation meet the minimum national requirements (according to Article 2b, paragraphs 2 and 3 of the Law on Academic Staff Development) and the additional requirements of Sofia University "St. Kliment Ohridski" for obtaining the scientific degree "Doctor of Physical Sciences" in Professional field 4.1. With at least 14 publications required, all 23 publications with which the applicant is participating in the procedure are from Group I (17 - from quartile Q1 and 6 - from quartile Q2). He is the leading author of 21 of them (minimum requirement - 9). Assoc. Prof. Ivanov participates in the procedure with 220 independent citations of his publications reflected in the dissertation, out of a total of 452 citations, which form an h-index of 12 (with a minimum requirement of 6). The data clearly show that the minimum national requirements and the specific requirements of the FoP are significantly exceeded in all criteria, typically by about a factor of two. The scientific publications included in the dissertation do not repeat those from the previous procedure for obtaining the PhD degree. The result of the check confirmed my belief that there is no evidence of plagiarism in the thesis and the abstract. The applicant has declared this also in the Declaration of Authorship attached to the documents.

The main interests of Assoc. Prof. Peter Ivanov are in the areas of quantum phase transitions, quantum metrology, the behavior of ions in Paul traps, in the field of quantum chaos and thermalization, and in the field of quantum information.

In this dissertation, multiparticle models, that exhibit a quantum phase transition and are often nonintegrable, but can be simulated with ions in Paul trap, are investigated. The quantum phase transition is described by an ordering parameter that changes at the transition point. Suitable conditions are realized as a low temperature, close to absolute zero, is achieved by using laser cooling, and parameter control is realized by applying additional laser fields. The idea of describing such processes is to use the mathematical similarity between a given model and simulations in a controlled quantum system. Such a system, which can be used for quantum simulations, is laser-cooled ions in a Paul trap (a quadrupole configuration of electrodes with applied one constant and a second fast (radio-frequency) oscillating electric fields leading to a stable harmonic minimum for the charged particle). In such a system, the applicant has described polariton excitations in a one-dimensional lattice. He has shown that the model describes a transition to a superfluid phase. He has also analyzed a model of a mixed ion crystal

consisting of particles with spins of different values. The phase diagram of the model was studied for a three-spin system. Of particular interest to me was Section 6, in which the "classical laser field" consists of photons with possibly non-zero orbital angular momentum. The applicant analyzed a method for transferring orbital angular momentum from an external laser field onto photons in an optical resonator, by using an atomic medium as a mediator in a stimulated Raman adiabatic transition. In the Laboratory of Femtosecond Photonics of the FoP a number of experimental methods for the generation of singular beams are developed that might be of interest to the applicant in his future work.

The second main direction of the research of Dr. Petar Ivanov is focused on critical systems with respect to their applications to quantum metrology. He has shown that systems that undergo a quantum phase transition can be used for ultraprecise quantum metrology - for the precise determination of an unknown parameter by a quantum system. The quantum phase transition leads to an abrupt change of the ground state of the system. In terms of information geometry, the distance between two close quantum states separated by a quantum phase transition can be very large. To define geometry between quantum states, the concept of distance as a measure of distinguishability must be introduced. In Section 7, a parameter is defined that characterizes how much two quantum states diverge with respect to an infinitesimally small change of parameters. Eq. 130 shows that this parameter has the form of a tensor. In Section 8, a quantum metrology protocol based on the quantum Dicke model is proposed, which more precisely predicts a quantum phase transition of the second kind. It is shown that a weak field that breaks the symmetry of the model can be measured with a Heisenberg precision. In Section 9, a quantum sensor for weak forces implemented with a single ion or a Paul trapped ion system is proposed. It is shown that forces on the order of 10^{-24} N can be measured by observing the temporal oscillations of the spin states of the ion(s). Section 11 is devoted to the measurement of low temperatures in a linear ionic crystal. After Doppler laser cooling (to about 100 μK), the application of a laser field allows the temperature information to be transferred to atomic populations. The temperature is determined by projective spin measurements. Rydberg atoms in optical resonators, which can be used to create topological phase transitions, are also considered. Section 12 is devoted to the emergence of quantum chaos in the Rabi model. Quantum chaos is associated with an exponential growth of the non-simultaneous correlation function. The Rabi model exhibits a quantum phase transition in the effective thermodynamic limit.

4. Teaching activity of the applicant

The teaching and the pedagogical activity of Assoc. Prof. Petar Ivanov is related to lectures and seminars in Quantum Mechanics for students in Medical Physics, for students in the

BSc-program Quantum and Theoretical Space Physics - to the courses in Methods and Applications of Quantum Mechanics and in Theoretical Mechanics. He has also taught a course on Quantum Simulations and Quantum Metrology for the MSc program in Quantum Informatics and an elective course on Quantum Phase Transitions. There are no data presented for diploma students supervised by Assoc. Prof. Petar Ivanov, but, upon request, I was given information on six students successfully graduate under his supervision.

5. Analysis of the applicant's scientific and application-related achievements contained in the submitted materials

The scientific contributions of the Dr. Petar Ivanov are in the field of theoretical quantum mechanics. I am evaluating them as creation of new theories and formulation of new hypotheses, significantly enriching the knowledge in the field. In the concluding part of his dissertation, the applicant is mentioning an experimental work from about 10 years ago in which a quantum phase transition of polaritons in an ionic crystal is demonstrated, and this work follows a theoretical publication co-authored by him. The total number of citations of the publications of Assoc. Prof. Petar Ivanov is 452, 220 of them are citations of papers included in this thesis. Considering his publication activity in the last few years, I believe that his results will continue to be duly reflected in publications of foreign research groups.

6. Critical remarks and recommendations

I have no critical comments on the dissertation. The abstract reproduces the dissertation almost completely, which is not usual. The completeness of the information in the abstract and, in general, the literary awareness of the applicant are, for me, beyond any doubt. The CV is four pages long, followed by pages which are not relevant to the material and should be removed.

7. Personal impressions from the candidate

My personal impressions are of a highly motivated and capable young professional, who grew up in the group of Professor Nikolay Vitanov, who took his own path in science and is enjoying the respect of his colleagues.

8. Conclusion

After I got acquainted with the submitted dissertation, with the abstract and with the other materials, based on the analysis of their significance and scientific and applied contributions contained therein, herewith I confirm that the scientific achievements fully meet and exceed the requirements of the Law on Academic Staff Development and the Regulations for its application and the relevant Regulations of the Sofia University "St. Kliment Ohridski" for obtaining the scientific degree "Doctor of Physical Sciences". In particular, the candidate exceeds (typically twice) the minimum national requirements in the Professional field 4.1. No plagiarism was found in the dissertation, abstract and scientific papers submitted for the procedure.

I give my positive evaluation of the thesis.

GENERAL CONCLUSION

On the basis of the above, I confidently recommend the Scientific jury to award to Assoc. Prof. Dr. Petar Aleksandrov Ivanov the degree of Doctor of Physical Sciences in the Professional field 4.1. Physical Sciences.

21.08.2022 г. …….....

(Prof. Dr.habil. Alexander Alexandrov Dreischuh)